AD4ON: An ITS-based Decision Making Architecture for Opportunistic Networking

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***Abstract*—To participate in smarter transportation systems, vehicles need to increase their environment awareness. This could be achieved by enabling vehicles to communicate with their environment. Once vehicles become connected, an ecosystem of applications and services could be developed around them, enabling the information exchange with other connected devices and contributing to a Cooperative Intelligent Transportation Systems (C-ITS). The environment of connected and cooperative vehicles is characterized by its heterogeneity. Numerous stakeholders are involved in providing various services, each of them with specific requirements. Moreover, countries may have specifics regulations. Therefore, a single access technology to connect all these heterogeneity is impossible. For ubiquitous connectivity it is necessary to use existing wireless communication technologies such as vehicular WiFi (ITS-G5, DSRC), urban WiFi, 802.15.4, and cellular. In such heterogeneous network environment, applications and services cannot take into account all technology particularities. A ITS communication architecture should hide to the application the underlying differences of access networks, providing seamless communication independently of the access technology. Based on the ITS architecture designed by International Organization for Standardization (ISO) and European Telecommunications Standards Institute (ETSI), we proposed the AD4ON, a modular decision maker architecture capable to choose the best available communication profile and path for each data flow in an heterogeneous and dynamic network environment. The proposed architecture manages requirements and preferences from different actors (e.g., applications, users, administrators and regulators). It considers the context information (e.g., vehicle speed, battery level), and it takes into account the route conditions between two communicating devices. It could make proactive decision taking into account short-term previsions about the network environment.**

***Keywords*—ISO TC 204; ETSI TC ITS; ITS station communication architecture; C-ITS; decision making.**

I. Introduction

The number of connected devices is growing fast around the world. According to Cisco Visual Networking Index (VNI) forecast, there will be more than 20 billions of connected devices by 2020 [2], i.e., an average of 3.2 devices per capita. These objects are components of a network known as the Internet of Things (IoT), where each object has the possibility to acquire and exchange data with others. This scenario enables the development of smart cities, where vehicles are supposed to be one of the communicating objects. According to Gartner research company, connected cars would be a major element of the IoT [3].

To participate in smarter transportation systems, vehicles need to increase their environment awareness. This could be achieved by enabling vehicles to communicate with their environment. Such connection could be local between nearby devices or global, i.e., connection over the Internet.

Once vehicles become connected, an ecosystem of applications and services can be developed around them. Nowadays, we are connected to Internet through our computers and smartphones. In the future, the vehicles will be directly connected too, supporting a variety of applications just like smartphones do. For example, vehicles could connect to the Internet to enhance driver and passenger experience, improving the navigation services and offering on-board Internet connectivity. Vehicles can exchange information with other devices in a smart city environment in order to improve safety and driver assistance, e.g., preventing car collisions and enabling automatic emergency call services (eCall). In this context, users, devices and vehicles need to be connected anywhere, anytime with anything. Such connections will enable the information exchange between vehicles and their environment for a Cooperative Intelligent Transportation Systems (C-ITS).

However, a single access technology to connect all these heterogeneity of services and devices is impractical or even impossible. For ubiquitous connectivity it is necessary to use existing wireless technologies, such as vehicular WiFi (ITS-G5, and DSRC), urban WiFi (e.g., 802.11 ac, g, n), 802.15.4, WiMAX, cellular (3G, 4G, and 5G under preparation) [4]–[6]. Each of these networks has specific characteristics in terms of bandwidth, data rate, latency, security and others. Due to this network heterogeneity and its complementary characteristics, more connectivity opportunities are available. Mobile devices equipped with multiple communication capabilities can use multiple access technologies simultaneously in order to maximize flows satisfaction (e.g., to maximize communication bandwidth, to reduce latency, and others) and to satisfy communication requirements (e.g., security, monetary cost, traffic load balancing among available networks, and others).

The environment of connected and cooperative vehicles is characterized by its heterogeneity. There are a wide variety of applications, each one with specific requirements, e.g., safety services usually need low amount of bandwidth but are highly sensitive to delays, while entertainment services like video streaming need more bandwidth, but they are delay tolerant. There are a variety of users with different preferences.

Countries could have specifics regulations. There are a variety of access technologies, each one with specific characteristics in terms of bandwidth, data rate, security and others. Moreover, vehicles can move at high speed and frequently change its network environment.

In such heterogeneous and dynamic network environment, applications and services cannot take into account all technology particularities, unless they explicitly need it. The communication architecture has to hide to the application the underlying differences of access networks, providing seamless communication independently of the access technology. It should be capable to handle multiple access technologies simultaneously selecting the most appropriate access network for each flow. Such an architecture should choose the path, i.e., the route between two communicating nodes that best meets the communication requirements (e.g., a local connection between nearby devices or a global connection over the Internet). Moreover, in order to have seamless communication in such dynamic environment it is desirable to anticipate network changes, i.e., it is desirable that the communication architecture performs proactive decisions taking into account the short-term prevision about the network availability.

Based on our research, on the ITS architecture proposed by International Organization for Standardization (ISO) and European Telecommunications Standards Institute (ETSI) and a survey of the litterature, we identified the good properties such a decision mechanism should have. We propose here the Ant-based Decision Maker for Opportunistic Networking (AD4ON), a new Decision Maker (DM) architecture that meet such identified properties. Such DM architecture is capable to manage requirements and preferences from different actors (e.g., applications, users, administrators and regulators), it takes into account the short-term prevision about the network environment and it considers the context information (e.g., vehicle speed, battery level), in order to make proactive decisions. The proposed DM architecture is developed in an ISO/ETSI standard compliant way.

The remainder of this paper is organized as follows. Section II overviews main trends in attempts to establish an harmonized communication-centric architecture for Intelligent Transportation Systems (ITS). Section III reviews some related work. The proposed AD4ON architecture as well as its integration in the ITS-S communication architecture are described in Section IV. Section V concludes the paper and proposes future directions.

II. ITS STANDARDIZATION

In the absence of a standardized communication architecture, services tend to be developed in silos, i.e., services are developed in a self-contained system. Usually, these services are developed for a specific problem and use a specific communication technology. Data is formatted according to previously known constraints of such communication technology. It is the case for example for current services of fleet management, emergency call (eCall), electric vehicle charging and data collection. As a result of the silo approach, heterogeneous and isolated solutions are deployed. It is therefore challenging and expensive to leverage them to provide new services.

In order to enable interoperability between such different existing technologies and cooperation between services, standardization bodies and researchers have been working toward a convergent architecture. The IEEE standardization body defined a family of standards for Wireless Access in the Vehicular Environment (WAVE) [7]. The WAVE architecture is shown in Figure 1. Such architecture is mainly devoted to V2X communications, which are based on the IEEE 802.11 standard [8]. The WAVE architecture presents a management plan and the capability to manage multiple channels. Despite its capability to manage multiple channels, such set of standards is not able to exploit heterogeneous wireless access technologies.

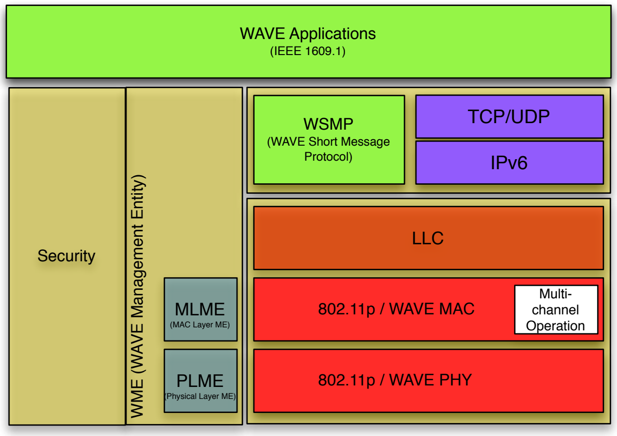

Figure 1. WAVE architecture

In order to establish an harmonized communication-centric architecture for ITS, ISO and ETSI have proposed a reference ITS communication architecture supported by nodes called ITS Stations (ITS-S), where each ITS-S (e.g., vehicles) can handle its communication through different access technologies [9]. This architecture is shown on Figure 2. The proposed AD4ON is based on such ITS architecture, and leverage on its capability to manage heterogeneous wireless access technologies.

The concept of the ITS-S communication architecture is to abstract applications from both the access technologies and the networks that transport the information between communicating nodes. Therefore, applications are not limited to a single access technology, but they can take advantage from all available technologies. While the lower layers can be independently managed without impacting applications.

In such architecture, two cross layers entities, i.e., “ITS Station Management” and “ITS Station Security” are responsible to station management functionalities and to provide security and privacy services, respectively. Since applications are developed regardless to communication networks, “ITS Station Management” entity is responsible, among others to choose the best network interface for each application. In

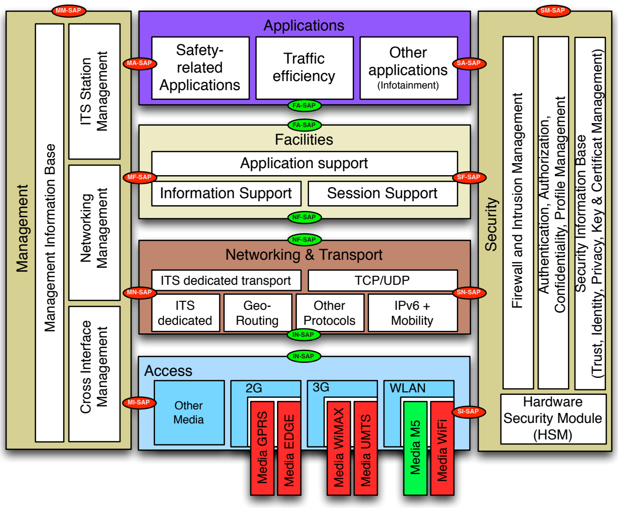

Figure 2. The reference ITS station communication architecture.

order to manage different process in the ITS-S, such cross layers entities communicate with the horizontal layers: “ITS Station Access Technologies” layer that is responsible for media access control and provides data transmission through different access technologies, such as vehicular WiFi (ITS-G5, DSRC), urban WiFi, 802.15.4, WiMAX, and cellular (3G, 4G, and 5G under preparation); “ITS Station Networking & Transport” layer, which is responsible to execute operations like packet routing, path establishment, path monitoring and Internet Protocol (IP) mobility; “ITS Station Facilities” layer that provides applications, information and communication supports (e.g., encode/decode message support, time-stamping and geo-stamping) and “ITS Station Application” layer that provides Human-Machine Interface (HMI).

Network Mobility Basic Support Protocol (NEMO) [10] has been chosen by several standardization bodies for IP-based mobility management, including ISO and ETSI. NEMO allows a Mobile Router (MR) to manage the IP mobility for all mobile network attached to it. The MR maintains a bi-directional tunnel (protected by IPsec) to a server in the cloud referred to as the Home Agent (HA), as shown on Figure 3. For the mobile network, it is allocated an IPv6 prefix identifying the mobile network in the IP addressing topology as permanently attached to the HA. Based on this prefix, the MR assigns unchangeable addresses to its attached nodes called Mobile Network Nodes (MNN). When a new network is available, MR generates a new auto configured IP address (Care-of-address (CoA)) within the new visited network and notifies them to the HA. Only the MR and the HA are aware of the network change, since MNNs remain connected to the MR through their permanent IP address.

MRs can be equipped with multiple communication interfaces. Multiple Care of Addresses Registration (MCoA) [11] is used to managed these communication interfaces simultaneously, as illustrated on Figure 3. MCoA enables the registration

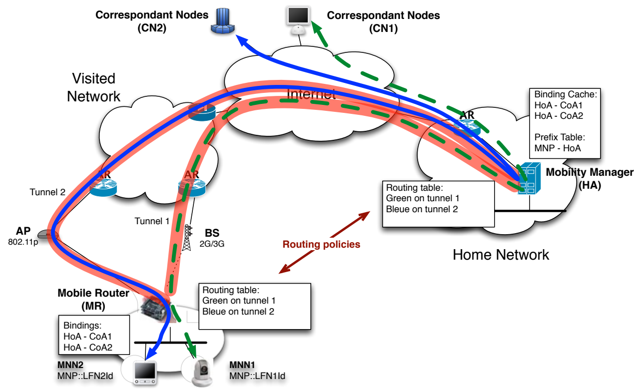

Figure 3. NEMO and MCoA.

of several CoAs for a single MR. In this case, the MR could establish multiple tunnels through each of its communication interfaces and the HA.

The possibility of having multiple applications in an ITS-S simultaneously competing for communication resources leads to the need for a controlled access to these resources. In such a control, requirements and objectives presented by application, user preferences, set of rules (e.g., regulations, network operator policies, etc.) and communication protocols’ status are used by the ITS-S Management Entity (SME), from “ITS-S Management” cross layer, to select the best suited communication profile and path per communication source. The determination of the path implies the selection of the communication interface, the logical node in the access network to which the ITS station is locally attached (ingress anchor node) and the intermediary nodes in the network used to reach the destination node (egress anchor node). Aware about paths characteristics, the SME can choose the path that best meets the communication requirements (e.g., a local connection between nearby devices or a global connection over the Internet). The methods to determine the most appropriate path and to perform flow-interface mapping is implementation specific as it could be a competitive factor between stakeholders. It is thus not specified in the ISO standards.

III. Related work

Several researches have been worked on the development of a DM architecture for network selection in heterogeneous network environment. Authors of [12] proposed a modular architecture for multi-homed mobile terminals. In such architecture, a middleware interacts with “higher-layers” and “lower-layers”. The “higher-layers” gather the user and the administrator preferences, handle the applications’ requirements, and detect the current terminal capabilities. The “lower-layers” detect available access networks and provide real-time information about the interfaces and access network capabilities, as well as it handles the selection execution process, i.e., it maps the application’s flows on the preferred access network. It does not consider the path condition of a given flow between sender and destination nodes. It does not consider the near future of the network environment, i.e., the short-term prevision access network resources.

Paper [13] proposes a context-aware management solution to maximize the satisfaction of the applications while respecting the stakeholders policy rules. The proposed framework collect and combining policies from stakeholders (e.g., user, administrators and applications). Based on such policies and context information, it evaluates the network that better match the communication requirements. Once the best network is chosen, the flow routing is enforced on the device using NEMO and MCoA. Such architecture does not consider the path condition experienced by a flow or the near future of the network environment.

Paper [14] proposes a framework for supporting network continuity in vehicular IPv6 communications. Such framework follows the ISO/ETSI guidelines for the development of cooperative ITS systems and it is based on standardized technologies, such as NEMO protocol to provide an integral management of IPv6. However, it considers cooperation between mobile devices and networks based on the IEEE 802.21 standard (Media Independent Handover (MIH)), i.e., it considers that all networks support specific functionalities from IEEE 802.21 standard [15].

Authors of paper [16] propose a mobile IPv6-based mobility management framework in a C-ITS standard compliant way. This framework uses dynamic and static context information to network discovery and selection for Vehicle-to-Infrastructure (V2I) communication. The proposed system uses the Local Dynamic Map (LDM), a conceptual data storage entity, to store and manage context information [17]. It extends the structure of Cooperative Awareness Message (CAM) messages to acquire both network conditions and application context information. Then, such acquired information are stored in the LDM. Network information are acquired by cooperation between vehicles and networks by using IEEE 802.21 MIH or Access Network Discovery and Selection Function (ANDSF) signalling schemes [15], [18]. Based on the current vehicle speed and direction, the mobility manager calculates its prediction window, i.e., the geographical positions for which it wants to receive candidates access networks. The vehicle sends this prediction window to the Roadside Unit (RSU), which provides back the network context information. Based on such information the mobility manager makes predictive decision about wireless networks for the V2I communication. The decision making algorithm is based on Analytic Hierarchy Process (AHP) methodology. Like paper [14], this paper assumes that access networks support specific functionalities from IEEE 802.21 standard.

Based on the MIH abstraction layer, the author of paper [19] designed a cross layer framework to manage the mobility through heterogeneous networks. An entity called "Cross Layer Management Entity (XLME)" is designed between the application and transport layer. Such entity is responsible to take into account the application requirements during the decision process and to manage the interaction between lower and upper layers. When a change is detected in the network by the MIHF (e.g., new network detected), it verifies the new network efficiency based on the application requirements. If the new network meets application requirements, the handover is based on the RSSI, i.e., the handover is triggered only if the detected network is more efficient than the current one in term of RSSI. Despite to consider application requirements to list network alternatives for a given application, the decision is based only in the network signal level.

Paper [20] proposes an mobility management architecture in the case of network mobility handover, i.e., handover performed by a MR on behalf of Mobile Node (MN) attached to it. The proposed mechanism is based on the IEEE 802.21 standard to acquire context information about network environment. The architecture proposes some functional entities in the MR side. A handover manager module is responsible to make network selection, while a context information module is responsible to extracts context information from both attached users and neighboring radio access networks. Such acquired information are stored in a local MR database. It is supposed that mobile users attached to the MR are able to acquire context information. The handover manager module uses the context information stored in the MR database, as well as, context information from other networks and handover policies received from the core network, in order to perform network selection and start the handover process. Such paper considers that all networks have the capability to cooperate with the decision maker (e.g., using IEEE 802.21 standard).

According to paper [21], as MIH works on the link layer, application and user context information are ignored. This paper proposes a enhanced MIH framework by integrating information from application, user and network in the process of network selection. It designs some functional modules. A context aware module is responsible to acquire information from applications and user. Based on these acquired information and in link layer information from well know MIH entities, a handover control module is responsible to rank the network candidates and to select the best one. The enhanced MIH framework can trigger handover in both client and network side. The proposed architecture does not consider the path condition experienced by a flow or the near future of the network environment.

Paper [22] proposes the "Intentional Networking", a mechanism that considers applications characteristics for better network selection in heterogeneous network. This framework does not consider user preferences or administrator policies. It uses a network monitoring module called "scout", which periodically attempts to establish network connections, and measures the throughput and latency of the connection. Besides the network conditions received from "scout", the decision maker module receives application information. Applications can express two kind of information to DM module: information about the data size to be transmitted (small or large) and information about latency dependence, i.e., if application is delay sensitive or not. Based on such application information the decision maker sort the applications data in a predefined preference order, e.g., latency sensitive preferred over non latency sensitive. Therefore, when the decision maker is informed by "scout" module that a given network is able to send data, it pulls data from the first application in the sorted list. When none of available networks matches with applications requirements, applications' flow are delayed until an appropriate network becomes available. In this design, the decision maker does not handle input from multiple actors. It considers only a limited number of application requirement.

Paper [23] proposes a framework to network selection based on applications QoS and user preferences. First of all, a preference specifier module acquires application requirements (e.g., bandwidth, delay, jitter) and user preference (e.g., how much the user is willing to pay for a given communication). A score calculator module receives such application requirements, user preference and networks conditions in order to produce exploitable scores for each potential application-network mapping. Finally, a load distribution module considers all these inputs to choose the best network for each application, while it performs load distribution among the interfaces. This framework does not consider the near future of the network environment.

Authors of paper [24] propose a shim layer between the network layer and the MAC layer of the Open Systems Interconnection (OSI) layered data model. This shim layer adapts flows to the available lower layers while make lower layers (i.e., MAC and Physical layer) transparent for applications. The proposed shim layer consists of a classifier, that receives packets from network layer and classifies it in five queues, according to theirs traffic types (i.e., video, voice, best-effort, background and safety critical); and a "Multi Interface Scheduling System (MISS)". The MISS module is responsible to distribute the queued packets across different Radio Access Technology (RAT). The distribution process is divided in two parts: called "scoring system" and "scheduler". In the scoring part, the MISS module considers application requirements, network conditions and user preference in order to assign a score for each application-network mapping possibility. The scheduler uses the previous calculated scores to distribute the packets among available RAT. The proposed architecture does not consider the near future of the network environment.

According to the literature review, researches have worked on the development of modular DM architecture. Most of proposed architectures suppose cooperation with the network side, for example by using specific functionalities from IEEE 802.21 standard. In this way, they consider that all networks support such specific functionalities. Moreover, although some solutions propose cross layer modules to hide applications from the wireless access technologies, few researches have been carried out in an ISO/ETSI standard compliant way.

IV. The ITS-based AD4ON Architecture

This section describes the modular AD4ON architecture for opportunistic networking in heterogeneous access network environment. The proposed architecture is based on the previously described ITS-S communication architecture and designed to meet the main challenges for communication profile and path selection in C-ITS environment. This architecture was first stretched in our previous work [1] and it is more detailed here.

A. *Expected properties*

As described in [25], the environment of connected and cooperative vehicles is characterized by a large heterogeneity. There are a wide variety of applications with different communication requirements. There are different wireless access technologies each one with specific characteristics in terms of bandwidth, data rate, security and others. In such an environment, the process to select the best suited communication profile and path for each data flow presents some challenges.

Different actors are able to present their requirements, preferences, constraints and policies in the decision making process. For example, applications can request a specific bandwidth, data rate or security level. Users can present their preferences, e.g., defining a priority or security level for a given message. Industrial and mobility service providers (i.e., operators) can present their policies, such as network constraints and particular billing procedures. Moreover, these wide variety of objectives could be contradictory. The DM architecture should be capable of managing these multiple objectives simultaneously.

Such an architecture should manage flow per flow, in order to select the most appropriate communication profile and path for each flow as well as to manage flow priorities.

The DM architecture should be able to monitor a variety of information in order to enable more accurate solutions in the decision making process. One essential piece of information to be monitored is the wireless networks availability as well as the performance of the networks in use. Moreover, it is necessary to monitor flows and their characteristics (e.g., used bandwidth, flow status).

Besides network monitoring, other significant parameters could be monitored. Vehicles would be able to take information from their environment, as vehicle's battery level, geographical position (e.g., GPS) or vehicle's speed in order to adjust the decision's strategies. For example, a power consuming network interface could be deactivated if the vehicle's battery level is under a certain threshold. Or a WiFi network could be privileged if the vehicle is stationary, while a cellular network could be preferred if the vehicle is moving.

The DM architecture should be capable of handling communication profile and communication path for each flow. A data flow is defined by ISO as an identifiable sequence of packets [26]. And packets are dependent upon applied protocols, links and nodes characteristics. For example, packets sent over different communication paths (routes) to the same destination node experience distinct network conditions/performances. Such distinct experiences are consequence of the applied protocol stacks (communication profile) and the specific characteristics of the traversed path (e.g., delay, throughput, security level, etc.). Therefore, on the Flow-Interface mapping process, it is not enough to indicate only what access network a given flow should use. In addition, according to flow requirements and paths characteristics it is necessary to determine the communication profile and path for each flow.

Moreover, due the vehicle's high speed the networks availability could change rapidly. In such highly dynamic mobility the decision making process should take into account the short-term prevision about the network environment condition. If the DM is aware about the near future of the network environment it can perform proactive and fine-grained decision. For example, it can decide to increase the data buffer for a given video streaming, if the vehicle is going to cross a wireless dead zone. Or, an on-board application could decide to delay a data transmission if it knows that a better network will soon be available.

The short-term prevision can be obtained in different ways. It can be obtained by cooperation with networks, e.g., using the IEEE 802.21 standard if the network support such protocol. The vehicle can store network information from a previous traversed route, e.g., for an user who uses the same route every day, the database could stores information about network conditions in such route. Or, the short-term information can be obtained by cooperation with neighbors vehicles. For example, two vehicles in opposite directions could exchange information about access points in their upcoming route. For this purpose, a vehicle stores the position of each access point in its traversed route, and give them to another passing-by vehicle.

B. Architecture design

To achieve the expected properties, we propose the modular AD4ON architecture based on the ISO/ETSI standards. Figure 4 shows such proposed DM architecture.

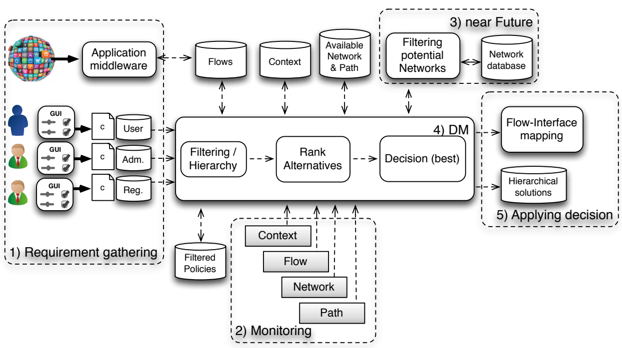

Figure 4. Proposed AD4ON Architecture.

For a better understanding, we split the DM architecture in five main parts, which are described below.

1) Requirement gathering: As mentioned before, different actors are able to present theirs requirements in the decision making process. In our proposed architecture we consider four main actors: applications, users, administrators and regulator bodies.

As defined by [27], applications can be divided in four different traffic classes: conversational, streaming, interactive and background classes. Each one of these classes has specific requirements in terms of Quality of Service (QoS). For example, conversational class groups real-time services like video telephony and VoIP calls, which are very delay sensitive while background class represents services like background downloads or e-mails, which are more delay tolerant. Services from interactive class, e.g., an online end-user requesting data from a remote server, usually have higher priority in scheduling than services from background class.

Therefore, applications can have specific requirements in terms of QoS. We defined four key performance parameters that each application should presents to the DM: the maximum supported end-to-end delay, the sensibility for information loss, the minimum required throughput and the security level, i.e., if information is sensitive and therefore must be protected from unauthorized access. A middleware enables applications to send their requirements to the DM.

According to the defined key performance parameters, applications do not need take care about underlying communication technologies, unless they explicitly need it. Instead, the DM manages such communication, enabling applications to take advantage of any available technology.

Users can have specific needs. Therefore, they can present their preferences through a Graphical User Interface (GUI), e.g., defining service priorities, security level for a given message or the amount of money they are willing to pay for a given service. Administrators, i.e., industrial and mobility service providers can present their policies, such as network constraints and particular billing procedures. Each country or region could define some specific rules, such as the prohibition of certain frequency ranges in certain areas. Therefore, regulator bodies can also express their policies.

Requirements, preferences and policies from all actors are stored in decision maker's databases and used by the DM to choose the communication interface that better matches the actors requirements.

2) Monitoring modules: We defined four monitoring modules. *Network monitoring module* - in this process, the network monitoring module listens to the wireless interfaces and informs DM about the available wireless networks and their performances. Such monitoring module should be able to monitor network information even if no specific monitoring functionality, such as IEEE 802.21 [15], is implemented on the network side. *Context monitoring module* - this module is responsible for vehicle surrounding monitoring. It is responsible to monitor information like location of the neighboring vehicles, traffic jam, vehicle's speed, and others. These information are part of the LDM functionalities, i.e., the conceptual data store located within an ITS-S as outlined in [17]. Therefore, we aim to rely this monitoring module on such conceptual data store. *Flow monitoring module* - this module should inform whether a flow is alive or not and evaluate flows' performance, like the currently used bandwidth, the currently latency, etc. *Path monitoring module* - this module is responsible to obtain various information (e.g., throughput, security level, latency, etc.) about the controllable end points where packets will be routed and to keep track of all the candidate and available paths.

3) Near Future: As mentioned before, due the high vehicle mobility, a connected vehicle changes their network environment constantly. A vehicle running in high speed can cross low-range network (e.g., urban WiFi) rapidly. Therefore, an available access network can be soon unavailable, or a vehicle can rapidly reach new access technologies coverage. In a such dynamic environment, if the DM is capable to anticipate networks conditions, it can perform a more fine-grained decision, as well as, offer a seamless communication. For example, if the DM knows that a network connection will be soon unavailable, it can decide in advance to reroute flows to another access network. Therefore, in dynamic environment, it is desirable a proactive DM mechanism capable to make decisions based on the near future about the network environment, which the vehicle is going to cross.

In order to take into account the short-term prevision about the network environment, we propose a network database that store the historical information about the access networks (e.g., network performance and access point location) and a filtering entity that is responsible to analyze such network database and, based on the context information of the vehicle (e.g., movement speed, vehicle position and movement direction), to choose the potential networks to be considered in the decision making process. Once the potential networks are listed, such information is sent to the "Rank Alternatives" module to be considered in the decision making process.

4) Decision making process: The decision making process is responsible to take into account the application's requirements, user profiles, administrative rules (regulation and policies) as well as different monitored information in order to manage flows and paths. The decision making process is detailed in Section IV-C.

5) Applying decision: In the applying decision process, the policies and information produced by the decision making process are applied in the system. In this process, the decision maker could interact with controlled entities in all layers of the ITS station communication architecture. Once the best access network and path is selected, i.e., the path and access network that better match the communication requirements, the DM request the "Flow-Interface mapping" module to enforce the flow routing decision. To enforce the decision's polices at the network layer in an IP-based environment, we are considering NEMO and MCoA. These protocols allow mobile routers to manage multiple access technologies simultaneously and to improve path and flow management.

Since the decision making process take into account the short-term prevision about the network environment, proactive decisions are enforced in order to maintain flows always best connected. However, unexpected changes can occur in a wireless environment (e.g., a given access network can drops). In order to adapt to the network conditions in real time, the DM maintain an hierarchical solution database with all sub-optimal solutions for each flow. This database is used by the "Flow-Interface mapping" module in case of emergency, i.e., when the best network solution drops unexpectedly and until the DM finds another better solution.

C. Decision Making Process

As mentioned before, the decision making process takes into account the application's requirements, user profiles, administrative rules as well as information from a variety of monitoring modules in order to manage flows and paths. We split our decision making process in three modules, as shown on Figure 4. Below we describe each one of these modules:

Hierarchy/Filtering: This module is responsible to receive and manage requirements, preferences, and policies from different actors. Since actors may have their own specific preferences and requirements, we need to "filter" (in Computer Science acceptation) the various values defined for the same parameter. Moreover, it is necessary to define a priority order between actors in order to manage contradictory objectives. For example, if the administrator sets a forbidden network for a user, and the user set the same access network to preferred, then it is necessary to define who has the priority. The output of such module is a list of filtered and hierarchical requirements.

Rank Alternatives: This module is responsible to find all alternatives for flow-interface mapping. It is a first filter to avoid forbidden networks or networks that do not match with flows' requirements. Such module receives the coherent list of requirements from "Hierarchy/Filtering" module, network information (e.g., networks availability and networks performance), and context information in order to find the potential solutions. The output of this module is a list of all potential solutions for each flow.

Decision Algorithm: This module receives the list of all potential solutions created in the "Rank Alternatives" module and apply decision making algorithm in order to evaluate the matching degree of communication requirements with networks and path characteristics. An utility function calculates a score, representing the matching degree for each solution. Higher the score, better is the solution. The solutions are sorted by descending order of score and stored on the hierarchical solution database. Such database is used by the enforcement module in case of emergency, i.e., when the best network drops unexpectedly, the "Flow-Interface mapping" module redirect the flow through the first available sub-optimal network while the DM finds a new better solution.

As described by [25], several decision making algorithms have been used in the network selection process. For example, the ones based on the game theory, the ones based on Multi-Objective Optimization (MOO) and the algorithm that uses Multi-Attribute Decision Making (MADM) techniques. The most used are the MADM methods (e.g., Simple Additive Weighting (SAW), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and AHP). Despite the MADM techniques present advantage as relative low computation complexity, this approach has some issues. For example, it is very difficult to choose the best weight for each attribute. Moreover, MADM algorithms could present ranking abnormality, i.e., change in one of the parameters of the objective function could determine a very different best solution.

The existing decision making algorithms do not meet our needs. Therefore, we are working in a new decision making algorithm that is capable to take advantage of the entire proposed architecture. The new algorithm presents the following properties. It can find high-quality solutions in a reasonable time. It is a memory-based algorithm, i.e., new solution can take into account previous status of the network environment. In this way, we can prevent full recalculation when only few network parameters changes. The new algorithm is run-time adaptable, i.e., it adapts to the network conditions and vehicle context. Moreover, solutions are created smoothly over time, i.e., the decision making algorithm is capable to prevent "ping-pong" effect.

However, the design of a decision making algorithm is outside the scope of this paper. Such topic will be addressed in future works.

D. Integration in the ITS-S communication architecture

The ITS-S communication architecture functionalities could be implemented into a single physical unit or distributed into several physical units. The paper [28] presents a real implementation into a single physical unit based on C-ITS standards. Once applied to a vehicle, these functionalities could be performed by different modules in the vehicle's electric/electronic architecture.

Moreover, the NEMO environment mainly separate the applications and communications into MNN and MR. Therefore, the five functions described in Section IV-B can also be separated into such nodes. For example, the requirement gathering can be implemented in the MNN, the monitoring modules can be implemented in both MR and MNN, while the near future, the decision making process and applying decision are functions of the MR.

The AD4ON architecture is designed in an ISO/ETSI standard compliant way. Figure 5 shows one way how we can integrate such architecture in the ITS-S communication architecture.

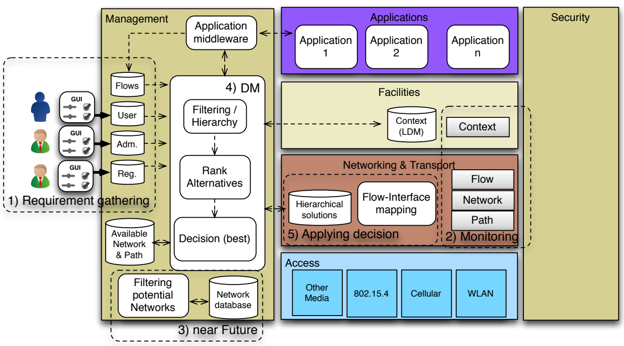

Figure 5. Integration of DM Architecture in the ITS-S communication architecture.

However, the standards give some guidelines to the developers, leaving some room in the way to implement the ITS-S communication architecture.

The AD4ON can interact with controlled entities in all layers of the ITS station communication architecture. Such communication is performed towards standardized interfaces between the different layers. In the following we describe two of these interfaces: the MA-Service Access Point (MA-SAP) – interface between the ITS-S application layer and the ITS-S management layer; and the MN-Service Access Point (MN-SAP) – interface between the ITS-S management layer and the ITS-S network & transport layer.

ISO 24102-3 [29] classifies Service Access Point (SAP) in two types, according to who initiate the service. Services initiated by the ITS-S management layer are known as "*Commands*" while the ones initiated by the ITS-S application layer or ITS-S network & transport layer are known as "*Request*". Furthermore, each one of such classification has two service primitives: one to trigger an action (i.e., "*request*") and another one to report the results of the performed action (i.e., "*confirm*"). Figure 6 depicts such classification.

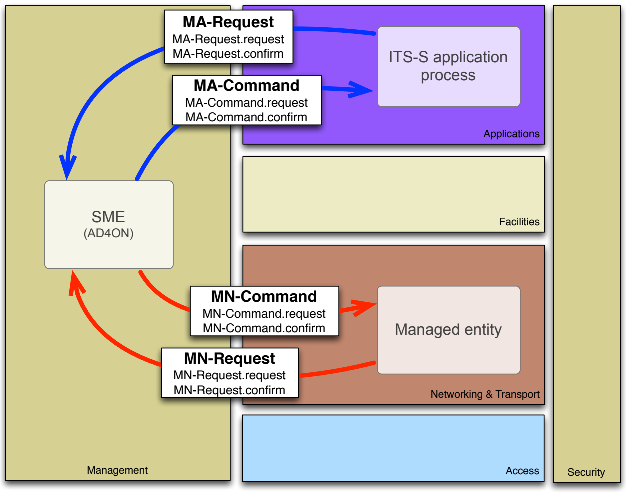

Figure 6. Communication towards MA-SAP and MN-SAP.

The AD4ON is placed in the ITS-S management entity. Therefore, in order to communicate with controlled entities in other ITS-S layers, we use the service primitives defined by ISO. Such service primitives are detailed below.

1) MA-SAP: This service access point is used for communication between ITS-S application layer and ITS-S management layer. As shown on Figure 6, the MA-SAP has four service primitives: *MA-Request.request*, *MA-Request.confirm*, *MA-Command.request*, and *MA-Command.confirm*. Since the primitives follow the same framework, in the following we show primitive structure only for *MA-Request.request* and *MA-Request.confirm*. The others are supposed to use similar structure.

When an ITS application process needs to trigger an action in the DM, it sends the *MA-Request.request* service primitive.

For example, an application uses such primitive to present its communication requirements to the AD4ON. The structure of such primitive is showed on Figure 7, and the arguments used by the MA-Request-request service are described on Table I.

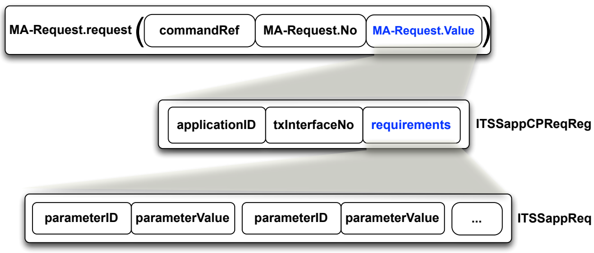

Figure 7. The structure of the *MA-Request.request* service.

Table I. Parameters of the MA-Request-request service

Name	Description
commandRef	Unique cyclic reference number of command
MA-Request.No	Reference number of the request
applicationID	Identifier of an ITS-S application process. Specified in ISO 24102-1 [30]
txInterfaceNo	Sink or source of an ITS-S application process. Specified in ISO 17419 [31]
parameterID	Integer values predefined for each parameter. E.g., 15 indicates minimum throughput, 17 indicates maximum acceptable latency, and 29 indicates priority flow parameters. Specified in ISO 17423 [32]
parameterValue	Values assigned for each parameter

Once the action requested by the application is performed by the DM, it replies the application with the *MA-Request.confirm* service primitive. The structure of such service primitive is showed on Figure 8, and its specifics arguments are described on Table II.

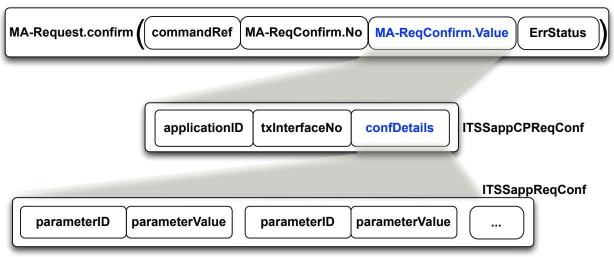

Figure 8. The structure of the *MA-Request.confirm* service.

Table II. Parameters of the MA-Request-confirm service

Name	Description
MA-ReqConfirm.No	Reference number of the request. Same value as MA-Request.No in related *MA-Request.request*.
ErrStatus	Values predefined in ISO 24102-3 [29]. E.g., (0) success, (3) invalid parameter value, and (10) value not available.

Following the same reasoning, the *MA-Command.request* service primitive allows the ITS-S management entity to trigger an action at the ITS-S application layer. For example, such primitive enables the AD4ON to alert adaptive application about network conditions. The arguments used by the MA-Command-request service are described on Table III.

Table III. Parameters of the MA-Command-request service

Name	Description
commandRef	Unique cyclic reference number of command
MA-Command.No	Reference number of command.
MA-Command.Value	Value of command.

Once the action is performed by the application, it replies the DM with the *MA-Command.confirm* service primitive.

2) MN-SAP: This service access point is used for communication between ITS-S network & transport layer and ITS-S management layer. Similarly the MA-SAP, the MN-SAP has four service primitives: MN-Request.request, MN-Request.confirm, MN-Command.request, and MN-Command.confirm.

When modules in the ITS-S network & transport layer needs to trigger actions in the DM, it uses the MN-Request.request service primitive. For example, network monitoring module located in the ITS-S network & transport layer uses such primitive to send information about network performance to the AD4ON in the ITS-S management entity.

The arguments used by the MN-Request-request service are described on Table IV.

Table IV. Parameters of the MN-Request-request service

Name	Description
commandRef	Unique cyclic reference number of command
MN-Request.No	Reference number of the request. E.g., 2 indicates the `FWTsetNot` command, 3 indicates the `FWTupdateNot` command, and 4 indicates the `FWTdeleteNot` command
MA-Request.Value	Value of the request

Once the action is performed by the ITS-S management entity, it replies with the MN-Request.confirm service primitive.

The management service primitive MN-Command.request allows the ITS-S management entity to trigger an action at the ITS-S network & transport layer. For example, such primitive enables the AD4ON to enforce a decision in the network layer. The arguments used by the MN-Command-request service are described on Table V.

Table V. Parameters of the MN-Command-request service

Name	Description
commandRef	Unique cyclic reference number of command
MN-Command.No	Reference number of the command.
MN-Command.Value	Value of the command

Once the action is performed by the ITS-S network & transport layer, it replies the DM with the MN-Command.confirm service primitive.

Therefore, using standardized service access points, the AD4ON can interact with controlled entities in all layers and select the most suitable communication profile for each application, i.e., select a collection of facilities protocols, transport protocols, network protocols, access technologies and communication channels that are used for a given data flow. For example, the AD4ON can request the "ITS-S Facilities" layer to encode, decode or time-stamping a given message. It can apply route decisions in the "ITS-S Networking & Transport" layer and take advantage of IP mobility management (e.g., using NEMO protocol and MCoA).

V. Conclusion and Future Work

According to the literature review, researchers have worked to propose an architecture for network selection, in which applications can take advantage of available access technologies. For example, some solutions propose to add new sub-layers within the well-know OSI model in order to hide specificities of wireless access technologies to applications. Moreover, efforts have been made to performs more accurate decisions, for example by cooperating with the network side (e.g., by using IEEE 802.21 MIH).

In this paper we proposed the AD4ON, an ISO/ETSI-based decision making architecture that is capable to choose the best available communication profile and path for each data flow in an heterogeneous and dynamic network environment.

Different actors are able to present theirs requirements in the decision making process, e.g., applications, users, network administrators, etc. And this wide variety of objectives could be contradictory. The AD4ON architecture is capable of managing these multiple objectives simultaneously. Moreover, the DM receives information from a variety of monitoring modules (network, context information, path, and flows monitoring modules), that enable fine-grained decisions.

According to the defined key performance parameters, applications do not need to be aware about underlying communication technologies, unless they explicitly need it. Instead, the AD4ON handles the communication side to maximise satisfaction of all flow sharing communication media. Therefore, applications are not limited to a single access technology, but they can take advantage of all available technologies.

Besides the access network selection, the proposed architecture is able to choose the best path for a given flow, i.e., the route between two communicating nodes that best meets the communication requirements (e.g., a local connection between nearby devices or a global connection over the Internet).

The proposed architecture address the short-term prevision about the network environment. This short-term prevision allows proactive decisions, which is very useful in vehicular environments that are characterized by its highly dynamic mobility.

Once the best access network and path is selected for a given flow, the decision's polices are enforced at the network layer using standardized protocols, such as NEMO and MCoA. These protocols allow mobile routers to manage multiple access technologies simultaneously and to improve path and flow management.

The AD4ON architecture is based on the ISO/ETSI ITS-S communication architecture, due the latter's capability to manage heterogeneous access technology. Since standards leave some room in the way to implement such architecture, in this paper we propose one way to integrate the AD4ON in the ITS-S communication architecture. Moreover, service primitives defined in an ISO/ETSI standard way enable the interoperability between controlled modules in different layers.

Based on the state of the art and in our previous work [1], the most used decision making algorithms do not meet our needs. Therefore, we are working in a new decision making algorithm that present the following properties. It can find high-quality solutions in a reasonable time. It is a memory-based algorithm, i.e., new solution can take into account previous status of the network environment. In this way, we can prevent full recalculation when only few network parameters changes. The new algorithm is run-time adaptable, i.e., it adapts to the network conditions and vehicle context. Moreover, solutions are adapted smoothly over time, i.e., the decision making algorithm is capable to prevent "ping-pong" effect.

In order to meet such properties, the new decision making algorithm is based on the Ant Colony Optimization (ACO) algorithm, a swarm intelligence class of algorithms. This class of algorithms are based on the collective and cooperative behaviors of ants, which are capable to find high-quality solutions for complex combinatorial optimization problems in a reasonable time.

We highlight the importance of the AD4ON architecture validation. As future work, we will simulate the proposed architecture using different scenarios and existing decision making algorithms. We will also simulate our new ant-based decision making algorithm, which is capable to take advantage of the entire proposed architecture for smart and fine-grained decisions. Moreover, it will be valuable to performe extensive evaluation of this architecture in a real test-bed.

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